RF LEVEL STABILIZATION OF OPTICAL LINK OVER TEMPERATURE

BACKGROUND OF THE INVENTION

1. Technical Field

The present invention relates generally to an optical link and more specifically to stabilization of the radio frequency (RF) level of the optical link. A method is also disclosed for utilizing the disclosed system for stabilization of the radio frequency (RF) level of the optical link.

2. Related Art

It is well known that the efficiency of a laser drops over temperature. It is also known that there exists a tracking error that prevents an exact track of the output levels of the laser over temperature. Due to a combination of these two factors, it is observable that the radio frequency (RF) level of an optical level changes significantly over temperature. The above issue affects the modulation depth that is perceived by the laser, which results in the same RF power affecting the laser and inducing certain extra noise conditions such as Rayleigh noise, *etc.*, under certain conditions.

In a typical optical link, such as, *inter alia*, that found in a cable television (CATV) transmission system having a transmitter section and a receiver section, the RF

level in the transmitted signal will vary with four parameters, namely, the laser temperature; the transmission link distance; the RF input changes to the transmitter section; and the overall transmission system gain.

The RF level at the receiver section will depend mainly on only two parameters, the optical modulation index (OMI) of the laser; and the optical power at the receiver section. However, to a lesser extent, the RF level also depends on the receiver section sensitivity, which changes from wavelength to wavelength; and the matching gain, which is an RF design issue.

SUMMARY OF THE INVENTION

It is therefore a feature of the present invention to overcome the above shortcomings related to optical links by providing a novel apparatus and method for maintaining the RF level stability over an optical link regardless of the temperature variation.

The present invention seeks to reduce the RF level stabilization over temperature utilizing two concepts. First, on the transmitter section end, the invention seeks to maintain the product of the optical modulation depth and the output power constant. On the receiver section end, appropriate circuitry is utilized to pick up and restore any RF level that was not maintained at the transmitter section.

The invention relies on the realization that the product of the laser OMI and the output power impacts the RF level. Accordingly, on the transmitter section side, a sub-

5Mhz carrier is impressed prior to the laser. This modulation is then simultaneously picked up by the laser rear face photo diode monitor and the receiver photo diode. The invention then maintains the RF level of the optical link constant by a combination of control of both the transmitter section front end and the receiver section front end. The advantage of the above procedure is that it monitors the RF level independent of loading on the transmitter, significantly reduces Rayleigh noise in sparsely loaded return systems, and provides mechanics to control the RF level on both the receiver and transmitter ends which is essential to maintaining the optical link below clipping behavior.

The present invention uses three feedback loops in the transmitter section and two feedback loops in the receiver section to both change, when necessary, and maintain at a particular level, RF levels related to an optically transmitted signal. The present invention further allows the following six functions may be performed simultaneously:

1. Preserve or change OMI;
2. Maintain output power;
3. Compensate for temperature changes;
4. Compensate for laser or system tracking errors
5. Provide gain at the right place, that is, in the transmitter section or the receiver section, as needed; and
6. Provide for RF input changes.

Finally, the apparatus and method of the present invention may also be used for any laser system, and in particular for Dynamic Noise-power-ratio (NPR) Boost (DNB) or

enhancement as disclosed in related US patent application no.(later), filed July, 2001, and incorporated herein by reference.

In a first general aspect, the present invention provides an apparatus for maintaining a stable RF level in an optical link, said apparatus comprising: a transmitter section; a receiver section; a plurality of feedback loops operationally connected to said transmitter section; and a plurality of feedback loops operationally connected to said receiver section.

In a second general aspect, the present invention provides a method of stabilizing an RF level in an optical link, said method comprising: providing an optical signal transmitter section; providing an optical signal receiver section; providing a plurality of feedback loops to said optical signal transmitter section; and providing a plurality of feedback loops to said optical signal receiver section.

In a third general aspect, the present invention provides an optical transmission system comprising: an optical signal transmitter section; an optical signal receiver section; an RF stabilization system operationally connected to said optical signal transmitter section; and an RF stabilization system operationally connected to said optical signal receiver section.

The foregoing and other features and advantages of the invention will be apparent from the following more particular description of embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and inventive aspects of the present invention will become more apparent upon reading the following detailed description, claims, and drawings, of which the following is a brief description.

Figure 1 is a block diagram representation of a current stabilization system according to an embodiment of the related art.

Figure 2 is a block diagram representation of a basic RF level stabilization system according to an embodiment of the present invention.

Figure 3 is a block diagram representation of an enhanced RF level stabilization system according to an embodiment of the present invention.

Figure 4 is a block diagram representation of a full RF level stabilization system according to an embodiment of the present invention.

Figure 5 is a block diagram representation of a functional RF level stabilization system according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The following is a detailed explanation, with reference to the attached drawings, of the apparatus for RF level stabilization of an optical link over temperature variations, and a method for using the apparatus for RF level stabilization of an optical link over temperature variations, in embodiments of the present invention. It should be noted that the same reference numbers are assigned to components having approximately the same

functions and structural features in the following explanation and the attached drawings to preclude the necessity for repeated explanation thereof.

Figure 1 shows a block diagram representation of a current stabilization system **100** for an optical link according to an embodiment of the related art. Current stabilization system **100** includes a transmitter section **102**, an optical link **150**, and a receiver section **105**. Transmitter section **102** includes an RF path comprising RF_{IN} amplifier circuit **110** and RF_{IN} attenuator circuit **120**, which are coupled to a laser transmitter **140**. Laser transmitter **140** is powered by supply voltage V_{cc}, and includes a laser device (*e.g.*, a laser diode) **142**, a bias input circuit **141**, and a back facet (BF) monitor circuit **143**. A first transmitter feedback loop **135** provides a bias current feedback signal **130** from BF monitor circuit **143** signal to the bias input circuit **141**. The bias current feedback bias signal **130** derived from the back facet monitor circuit **143** represents the DC current range of the laser device **142**.

The output signal from the laser device **142** is carried over optical link **150**, and is received by receiver section **105**. Receiver section **105** includes photo diode circuit **160**, which is controlled by optical modulation voltage (OMV) control circuit **161**, and powered by supply voltage V_{cc}. The output of photo diode circuit **160** is coupled to an RF path comprising RF_{OUT} amplifier circuit **170** and RF_{OUT} attenuator circuit **180**.

Optical link **150** may be comprised of, *inter alia*, erbium doped fiber amplifiers (EDFAS), semiconductor optical amplifiers (SOA's), and various kinds of optical fiber, such as, *inter alia*, single mode fiber (SMF) or dispersion compensating fiber (DCF).

An inherent drawback in the related art current stabilization system **100**, is that this current stabilization system **100** cannot compensate for two well known phenomenon, namely that the efficiency of a laser drops as temperature rises, and that tracking errors exist which prevent an exact tracking of the output level of the laser as the temperature varies.

Referring now to Figure 2, a block diagram representation of a basic RF_{IN} level stabilization system **200** according to an embodiment of the present invention. Basic RF_{IN} level stabilization system **200** includes a transmitter section **202**, an optical link **150**, and a receiver section **205**. Transmitter section **202** is similar to transmitter section **102** of the current stabilization system **100** of Figure 1. Receiver section **205** is similar to receiver section **105** of the current stabilization system **100** of Figure 1, except that receiver section **205** includes an added first receiver feedback loop **266**.

First receiver feedback loop **266** provides a feedback signal from the optical modulation voltage (OMV) control circuit **161** to the RF_{OUT} attenuator circuit **180**. The optical modulation voltage (OMV) control circuit **161** produces an feedback signal which is proportional to changes in the optical level of the photo diode **160**. First receiver feedback loop **266** includes a feedback attenuation circuit **265** to scale the feedback signal to a level compatible with RF_{OUT} attenuator circuit **180**.

This embodiment (Figure 2) compensates for changes in the optical power, including the tracking error. However, this embodiment cannot accommodate changes in the optical modulation index caused by changes in laser efficiency.

Figure 3 is a block diagram representation of an enhanced RF level stabilization system according to an embodiment of the present invention. Enhanced RF level stabilization system **300** includes a transmitter section **302**, an optical link **150**, and a receiver section **305**. Transmitter section **302** is similar to transmitter section **102** of the basic RF level stabilization system **200** of Figure 2, except that transmitter section **302** includes an added second transmitter feedback loop **336**. Receiver section **305** is similar to receiver section **205** of the basic RF level stabilization system **200** of Figure 2.

Second transmitter feedback loop **336** provides a feedback attenuation circuit **332** from the back facet monitor **143** to the RF_{IN} attenuator circuit **120**. The feedback attenuation circuit **332** produces an attenuated feedback signal which is proportional to the bias current from the laser. Second transmitter feedback loop **336** includes a feedback attenuation circuit **332** to scale the feedback signal to a level compatible with RF_{OUT} attenuator circuit **180**. Feedback attenuation circuit **332** may include a diode, transistor, or other attenuation circuit (*e.g.*, a PIN transistor circuit).

Figure 4 is a block diagram representation of a full RF level stabilization system according to an embodiment of the present invention. Full RF level stabilization system **400** includes a transmitter section **402**, an optical link **150**, and a receiver section **405**. Transmitter section **402** is similar to transmitter section **302** of the enhanced RF level stabilization system **300** of Figure 3, except that two additions have been made. First, an oscillator circuit **445** has been added to the output of the RF attenuator **120**. Oscillator circuit **445** introduces a signal tone of *e.g.*, 100 kHz or thereabouts. Second, a third

transmitter feedback circuit **430** has been added which provides a feedback loop from the back facet monitor **430** to the RF attenuator **120**.

Third transmitter feedback loop **455** provides a feedback signal from the back facet monitor **143** to the RF_{IN} attenuator **120**. Third transmitter feedback loop **455** includes a filter oscillator circuit, an RF detector circuit, and a feedback attenuator circuit. The RF in the transmitted signal is sensed by the RF detector circuit of feedback circuit **430** and is then fed to the feedback attenuator circuit which reduces or increases attenuation as needed.

Receiver section **405** is similar to receiver section **305** of the enhanced RF level stabilization system **300** of Figure 3, except that receiver section **405** includes an added second receiver feedback circuit **440** which provides a feedback loop from the photo diode **160** to the RF_{OUT} attenuator **180**. A signal from photo diode circuit **160** is fed to second receiver feedback circuit **440** which includes a filter oscillator circuit, an RF_{IN} sensor circuit, and a feedback attenuator circuit. The RF in the received signal is sensed by the RF detector circuit of second receiver feedback circuit **440** and is then fed to the feedback attenuator circuit which reduces or increases attenuation as needed.

Figure 5 is a block diagram representation of a functional RF level stabilization system according to an embodiment of the present invention. Functional RF level stabilization system **500** includes a transmitter section **502**, an optical link **150**, and a receiver section **505**. Transmitter section **502** is similar to transmitter section **402** of the full RF level stabilization system **400** of Figure 4, except that modulation and

demodulation circuits have been added to the transmitter section **502** and the receiver section **505**, respectively.

The modulation circuit **520** coupled to the oscillator circuit **445** of the transmitter section **502** enables the output signal from oscillator circuit **445** to be selectively varied, which in turn will selectively vary the output at node **410** of the RF_{IN} attenuator circuit **120**. This operation effectively tunes the output of the RF_{IN} attenuator circuit **120**, and hence the laser device **142**.

Similarly, the demodulation circuit **540** in receiver section **505** provides demodulation of the feedback circuit **440**.

Embodiments of the present invention have been disclosed. A person of ordinary skill in the art would realize, however, that certain modifications would come within the teachings of this invention. Therefore, the following claims should be studied to determine the true scope and content of the invention.